Bulletin of the *Transilvania* University of Braşov
Series VIII: Performing Arts • Vol. 17(66) No. 2 – 2024
https://doi.org/10.31926/but.pa.2024.17.66.2.7

Symphony of Space: where Architecture meets Melody

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Abstract: *This article explores the mathematical link between parametric architecture and music, revealing two key approaches to examining their relationship: conceptual and formal. The conceptual approach emphasizes space and its defining characteristics, while the formal approach delves into the physical forms by analyzing external and internal layers. Externally, it examines the relationship between frequencies, vibrations, and form creation. Internally, it focuses on the shared mathematical proportions in both music and architecture. Utilizing Ernst Chladni's cymatics experiments, which relate sound waves to geometric shapes, the research develops a mathematical formula to transform musical notes into two-dimensional forms. This quantitative approach demonstrates how both disciplines can be interconnected through mathematical language, algorithms, and geometry, offering insights into sound's structural representation. The study also suggests future directions for research, encouraging further exploration of the intersections between sound and architectural form in parametric design.*

Key-words: *Parametric Architecture, Music, Cymatics, Mathematics, Geometry, Algorithm*

1. Introduction

"Goethe believed that music is liquid architecture, and architecture is frozen music." Herbert Spencer, the English philosopher, says: All the arts are connected transversely because their origin is the manifestation of beauty (Sepehr and Poornirouzabadi 2012, 221). This connection also exists between architecture and music. In fact, architecture is music that happens in space, and music is architecture that happens in time; only the medium in which architecture and music occur differs. Additionally, architecture is created in a physical form with tangible materials, defining a functional space, while music has an immaterial and transcendent effect. Architecture is fixed and static, whereas music is dynamic and flowing.

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Architecture relies fundamentally on objective qualities to make a visual impact, evoke emotions, and stimulate feelings. In contrast, music fundamentally depends on auditory qualities, perceivable only through hearing, and it influences the inner world of the individual; Music expresses emotion through sound, while architecture creates material and spiritual spaces through matter. However, music encompasses only a spiritual space.

Architecture is three-dimensional, whereas music is one-dimensional; Music communicates directly and without mediation with its audience, making it easier to convey the artist's auditory messages, ideals, and emotions to others. In contrast, in architecture, the artist's message must be conveyed through an intermediary in the form of a building (Seraj 2013, 44). Although there are differences between architecture and music as two seemingly distinct artistic fields, such as those mentioned earlier, similarities can also be found that indicate a deep connection between them—a profound connection derived from a shared sense of space.

This is a space that both a musical piece and an architectural work can create, allowing one to experience an emotional sense in an architectural space that a piece of music can similarly evoke. Thus, within this shared space and by utilizing this deep connection, common concepts and elements can be derived, which can then serve as principles (or tools) to transform musical works into architectural works and vice versa.

Therefore, whether we like it or not, there is a connection between architecture and music, a connection rooted in our auditory structures, which are unified in these two arts (Xenakis 2011). Because the creation of architecture emerges from the same origin, passes through the same pathways, and ultimately reaches the same destinations as the creation of music. Perhaps this is why Goethe believed that 'architecture is frozen music' (Vaziri 2011, 3).

Broadly speaking, two approaches have existed in examining the relationship between music and architecture from past to present: the formal approach and the conceptual approach. The formal approach itself includes two perspectives: examining external and internal layers. (Figure 1) Parametric architecture, as a subset of digital architecture, uses geometry, mathematics, algorithms, and computers in the design problem-solving approach to control the design process. In mathematical sciences, a parameter is a quantity that defines specific characteristics of a system or function. It also serves as a means to link functions and variables through a common variable, especially when expressing a relationship with equations is challenging. In parametric architecture, the relationship between different design parameters is established through a defined algorithm, which is processed by a computer. An algorithm is a finite set of instructions executed in a specific order to solve a problem.

All arts are supported from conception to perception through mediums that manifest a specific art form. This article first briefly explores the connection between humans and art, then discusses the approaches to the relationship between architecture and music, identifies the common factor between parametric architecture and music, and examines the connection between the two.

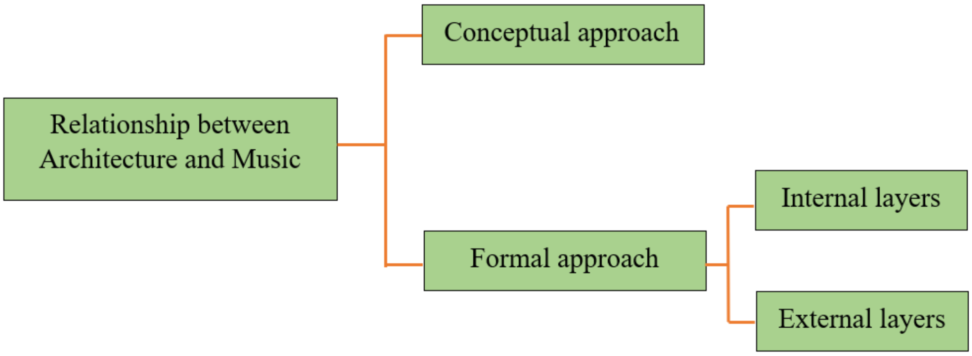


Fig.1. *The Relationship between architecture and music.*
Source: Authors

2. Theoretical Framework
2.1. Conceptual Interaction

In music, there is a term called “soundscape”, which represents the entire auditory landscape of the music, similar to the term "landscape" in visual arts and architecture, meaning scenery or panorama. If you take an overall look at an ideal architectural space, you’ll notice that various parts are balanced from different angles and contribute to the beautification of the whole. The same phenomenon occurs in music. Therefore, music and architecture share a common feature of placing us within a sensory space that is different from our usual living environment (Blesser and Salter 2009, 126). What emerges in the analysis phase of the creative process in art is the essence of a series of technical analyses, which ultimately take the form of imaginative and technical shapes, ready for expression and presentation (Nami 2011, 50).

At this stage, both architects and musicians make cuts on the formless material they have; stone is cut, and sound is shaped with specific tones, pitches, and durations so that it fits alongside the adjacent and preceding sounds. Building materials that have taken on a specific form, and sounds that have acquired particular pitch, resonance, and duration, are used to create two kinds of spaces (Pour Yousefzadeh 2013, 42). By considering "space" as the primary connecting factor between architecture and music, it can be said that once the artist—whether an architect or a musician (composer)—finds the space they envision for creating their work, they proceed to bring that space into existence through their creation. This is why an architect can evoke the same emotional and spiritual effects through creating various spaces that a musician can achieve with melodies and instruments. Just as a musical piece can, under the influence of the phonosphere (auditory space), create a spiritual atmosphere filled with reverent attractions, the structure of a mosque, its lofty minarets, or the elongated lines of a church can also inspire a sense of ascension and spirituality (Malih 2013, 39).

In this space, there are principles and concepts that architecture and music share, which can also be regarded as similarities between these two arts. These commonalities can be used as principles and tools for transforming musical works into architecture and architectural works into music. Some of these include rhythm, emphasis and accent, theme, harmony, color, symmetry, and proportion, a summary of which is presented in Table 2.

Concept	Music	Architecture	source
Rythm	Time-dependent and the sense of movement in music, which places considerable emphasis on order—a repetitive and cyclical order—and is also perceived through the variation in the strength and weakness of beats.	The orderly repetition of architectural elements along a continuum	Falamaki 1990 Seraj 2000
Accent	It is the observance of the accents and emphases of words in melodies that creates complete harmony between music and poetry.	manifesting a part of the structure in architecture	Dehlavi 1990, 142
Theme	the main theme of the song	architectural space, a collection of structural and conceptual characteristics	Feili Nejad 2006, 37
Harmony	Relationships between sounds, musical phrases, themes, and the resonance of instruments, etc.	Color, texture, shape, softness, roughness, and reflection can all be harmonious	Feili Nejad 2006, 37
Color	Qualitative factors of sound.	Qualitative factors of space	Feili Nejad 2006, 37
Symmetry	Ascending and descending of notes relative to a specific time	Visually, in relation to one or more specific axes.	Dehlavi 1990, 149

Concept	Music	Architecture	source
Proportion	The application of proportions over time, auditory ratios.	The application of proportions in spatial volume, height ratios.	Seraj 2001

Table 2. *Common concepts between music and architecture in conceptual approach*
Source: Authors

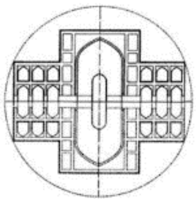


Fig. 2a. *Symmetry in music*
Source*:* Pouryousefzadeh et al. 2010, 40

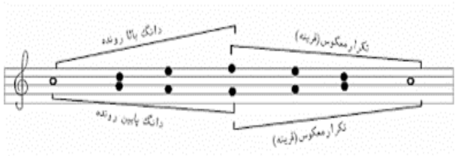


Fig. 2b. *Symmetry in architecture*
Source: Saremi 1990, 260

In addition, elements such as movement, stillness, climax and nadir, glissando, passage, chiaroscuro, contrast, and repetition are also shared qualities between these two arts. Grillo suggests an interesting table based on which various arts, including 'architecture' and 'music,' can be compared with one another. Grillo's proposed factors are as follows: Material, Unit, Scale, Rhythm, Dynamism (movement), Harmony (coordination). Each of these is explained separately in a table based on 'arts' and 'science.' (Only part of the table related to architecture and music is provided) (Seraj 2011, 165).

Architecture	Music	Proposed factors
Four types of materials: stone, organic, metallic, composite.	Four groups of musical instruments: wind, brass, string, percussion.	Materials
Tatami module in golden ratio.	Whole step / half step / quarter tone	Unit
Styles: Doric, Ionic, Corinthian, and Gothic proportions.	Modes: Major, minor, Lydian, Dorian, Aeolian, Chinese, etc.	Scale
Alternation of voids and volumes, colonnades, passages.	Signs, tempo markings (time), strong beat, status	Rhythm
Direction and orientation of forms, alignment of movement lines.	Row only in a specific direction (time), increasing dimensions.	Dynamism (movement)
Spatial division in the plan.	Harmonies, musical forms, and pleasant intervals.	Harmony (coordination)

Table 3. *Unity of the arts of music and architecture*
Source: Seraj 2010, 166.

2.2. Form interaction through the examination of outer layers

This type of approach is a purely superficial one that focuses only on examining the outer layers. One of the simplest examples of such approaches can be referenced by comparing the skyline of mountains and religious buildings to the peaks and troughs used in musical scales. One of the contemporary approaches to translating sound into a visual form is a method invented by Ernst Chladni in 1787. He first spread fine grains of sand on a plate and then caused it to vibrate using a violin bow. These vibrations caused the sand to create patterns, resulting in various shapes (Figure 3). Based on the results of this experiment, a science known as 'Chladni figures' emerged. The term 'wave' refers to mechanical waves, which are a subset of specific vibrational phenomena. This term was coined by Hans Jenny (1904-1972), a physician and natural scientist, to describe the acoustic effects of wave phenomena.

It is important to note that 'wave' refers to mechanical waves. Mechanical waves are generated by the propagation of disturbances through a material medium, and since their motion around their average position is periodic and repetitive, disturbances and variations transfer from one wave to another, similar to what Ernst Chladni did with the grains of sand.

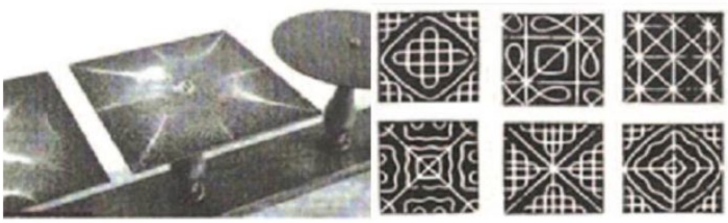


Fig. 3**.** *Formation of various patterns from sand due to vibrations produced by the violin*
Source: Jormakka 2009, 21

Today, many individuals interested in cymatics have conducted various experiments in this field, and the results have shown that each frequency of sound creates a unique form (Figure 4). Albert Einstein, the prominent German physicist, stated: 'Everything in life is vibration.' As you know, atoms, which are the building blocks of solids, liquids, and gases, are composed of electrons, protons, and neutrons, with electrons constantly revolving in specific orbits around their central nucleus.

In the field of acoustics, an English student named Tanya Harris, in pursuit of such an approach, studied the relationship between sound and geometry in terms of form for her master's thesis in cymatics. She examines four churches designed by the English architect Nicholas Hawksmoor. The experimental method involves recording the sound of silence in each church. The term 'sound of silence' refers to the sound that exists in the space but is not perceivable in the hearing domain. This phenomenon is justifiable based on Einstein's assertion that everything is in vibration and has a specific frequency. The results of the experiment were quite surprising. Each church produced a unique frequency, ultimately creating its own specific geometry (Figure 5).

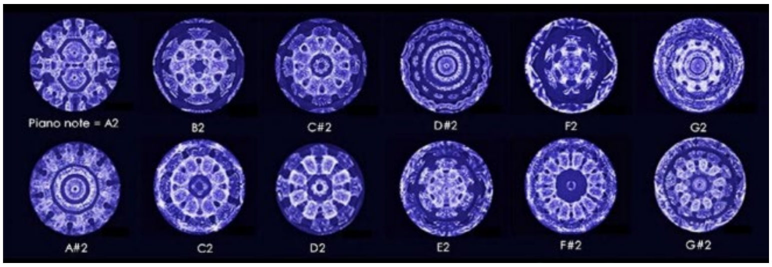


Fig. 4. *Forms produced by piano notes through a sound oscillograph*
Source: Cymascope.com

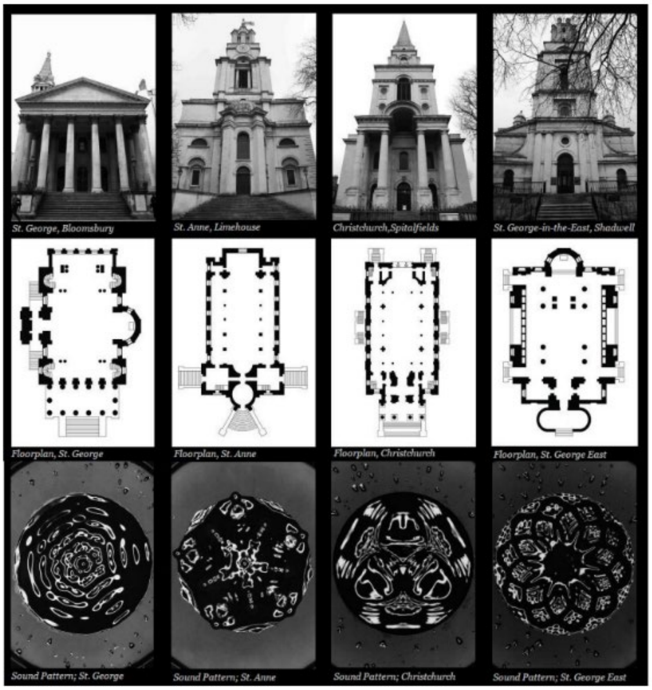


Fig.5. *Geometric form resulting from the sound of silence in four churches, based on Tanya Harris's experiment*
Source*:* http://www.tanyaharris.co.uk/architecture-of-sound

One of the other ways to transform music into architecture is by translating the temporal intervals of sounds into numbers. Wassily Kandinsky and Paul Klee were two artists who attempted to convert music into a visually perceivable form in this way. They selected Beethoven's Symphony No. 5 for this purpose, ultimately creating a set of visual diagrams (Jormakka 2009, 21-23). Another notable contemporary study in this field is the result of a digital design project by Chris Tensen. He developed parametric software incorporating numbers and ratios to generate 48 virtual forms based on the preludes from Johann Sebastian Bach’s Book I (Christensen 2005, 1) (Figure 6).

Another contemporary study was conducted by Martin Wattenberg. He used arc-shaped diagrams to translate some of the most famous musical works in the world into visual representations. In this study, he demonstrates that the relationships within pre-modern pieces contain many ellipses, unlike those in post-modern pieces, and he also compares them to diagrams derived from several well-known modern pieces (Wattenberg, 2009:5,6) (Figure 7).

Fig. 6. *Use of parametric software incorporating numbers and ratios to convert the preludes of Bach's Book I into virtual forms.*

Source: Jormakka 2009, 25

Fig.7. *Arc diagrams drawn by contemporary researcher Martin Wattenberg to display the musical structure of a modern piece (left image), Bach's G Major Sonata (middle image), and Beethoven's Für Elise (right image).*

Source: www.bewitched.com.

Researcher	Viewpoint / Function
Ernst Chladni	Vibration of sand particles on a glass surface through a violin bow.
Kandinsky - Paul Klee	Transforming music into architecture by translating the temporal intervals of sounds into numbers
Hans Jenny	The science of cymatics for describing the acoustic effects of sound wave phenomena.
Chris Tensen	Designing parametric software incorporating numbers and ratios to generate 48 virtual forms.
Martin Wattenberg	Using arc diagrams and converting music into charts for the analysis of each musical period.

The basis of the formal approach to outer layers is purely formal and expresses the relationship between frequency and vibration that leads to the formation of form.

Table 4. *Formal approach to the outer layers of music*

2.3. Formal approach to examining the inner layers

The general belief is that musical works are pleasant, lovable, and beautiful when they adhere to specific rules—rules that physics has recognized in terms of their technical aspects based on the sensitivities of the human ear and psyche, measured and evaluated over thousands of years on musical instruments (Falamaki, 2008:285). The same applies to architecture. The first to establish the inner relationship were Pythagoras and Plato. This approach focuses more on this topic. Pythagoras laid the foundations for hypotheses in mathematics, geometry, music, and ultimately architecture, which ultimately led to the expression of harmonious and cosmic ratios (Antoniades 2007, 454).

Just as the Greeks viewed music as geometry translated into sound, Renaissance architects believed that architecture was mathematics translated into spatial units (Ching 2007, 176). Georgiadis proves through his specialized perspective that visual or auditory harmony guarantees aesthetic pleasure. In contrast, Bartók blends the principles of ancient Greek architecture, such as the golden ratio and the five principles of Pythagoras, with the principles of acoustic harmony derived from Western European thought (Antoniades 2007, 446-452).

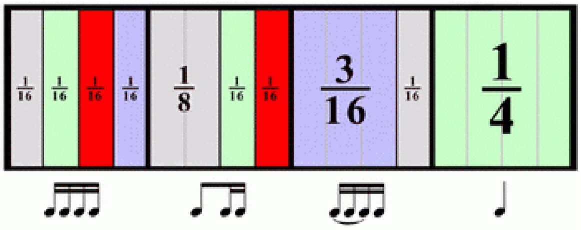


Fig. 7. *Mathematical harmonious ratios among four musical notes.*
Source: www.bewitched.com

One of the individuals who conducted serious research on the internal relationship between music and architecture in the modern era was Iannis Xenakis, a student of Le Corbusier. In his book 'Music and Architecture,' he emphasizes the role of geometry in integrating and bringing these two arts closer together, examining examples of music that have been transformed into architecture in his own work and that of other architects. Interestingly, he concludes in the final section of his book that 'the relationship between music and architecture is a virtual and theoretical one, not a real one' (Xenakis 2008, 312). Therefore, the basis of the formal approach in examining the inner layers is fundamentally based on the ratios that exist in common between music and architecture through the application of geometry (Table 5).

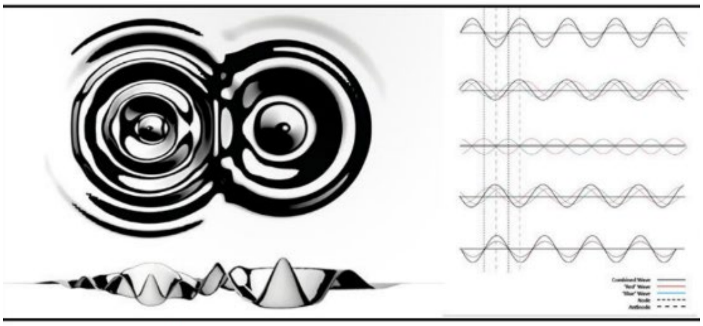
Researcher	Viewpoint / Function
Pythagoras-Plato	The relationship between mathematics, geometry, music, and architecture ultimately expresses harmonious cosmic ratios.
Greeks	Music is geometry translated into sound
Gorgias	Visual or auditory harmony guarantees aesthetic pleasure.
Bartók	The use of Pythagorean golden ratios in music
Iannis Xenakis	Emphasis on the science of geometry as a factor in aligning and connecting music and architecture The relationship between music and architecture is a virtual and mental one, rather than a real one

The basis of the formal approach to the inner layers is founded on the ratios that exist in common between music and architecture through the application of geometry.

Table 5. *Formal Approach to the Inner Layers of Music*

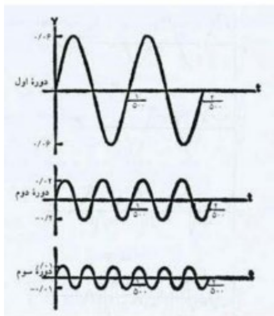
4. Discussion and analysis

What has been derived from the above studies is the existence of mathematical ratios in the intervals of musical notes and sound wave phenomena, which the science of cymatics has expressed as a tangible and unique manifestation for each frequency by utilizing its principles. Ernst Chladni's initial experiments, conducted using a sound apparatus, demonstrated this. Sound waves are classified as mechanical waves and require a material medium for propagation.



The graph related to the sinusoidal waves that constitute sound produced by the violin.

Source: Danesh, Mohammad. Art Born of Mathematics, 2013.



Each audio frequency creates a unique wave

Source: Jormakka 2009, 21

Fig. 9

By analyzing the principles of Ernst Chaldni's experiments and the science of cymatics, which are based on the wave properties of sound, a fundamental diagram emerges that illustrates how variable factors affect the wavelength and amplitude of waves. The result is a unique form for each frequency, identifiable by a sound visualization device. By analyzing the resulting forms based on the fundamental diagram, each form can be expressed with a foundational formula that transforms when variables are applied.

Parametric architecture, as a domain of digital architecture, utilizes mathematics and an algorithmic perspective on the design process by employing defined inputs as numerical variables, thus controlling the design stages, especially in terms of form, and generating outputs. Therefore, to digitally produce these forms with the help of parametric architectural structures that leverage mathematical principles and algorithmic processes, it is possible to create two-dimensional forms derived from each audio frequency based on the algorithmic definition rooted in the provided mathematical formula:

$$F(x, y) = Cos\left(\frac{m\rho x}{l}\right) Cos\left(\frac{n\rho y}{l}\right) + Cos\left(\frac{n\rho x}{l}\right) Cos\left(\frac{m\rho y}{l}\right)$$

In this formula, ***m*** and ***n*** are the input variables for the frequencies of the nodal vibrations. A node is defined as the geometric location of a point in a standing wavelength where the amplitude of the wave is at a minimum. For example, in a vibrating guitar string, there is a node at each end of the string, and the guitarist changes the position of these nodes by moving their hand along the strings, creating a new sound. ***l*** represents the length of the square base, and ***p*** denotes the density of the material on which the vibrations are applied. By altering the numerical values of the input variables ***m*** and ***n***, a variety of forms are created using the Rhino software in conjunction with the Grasshopper plugin.

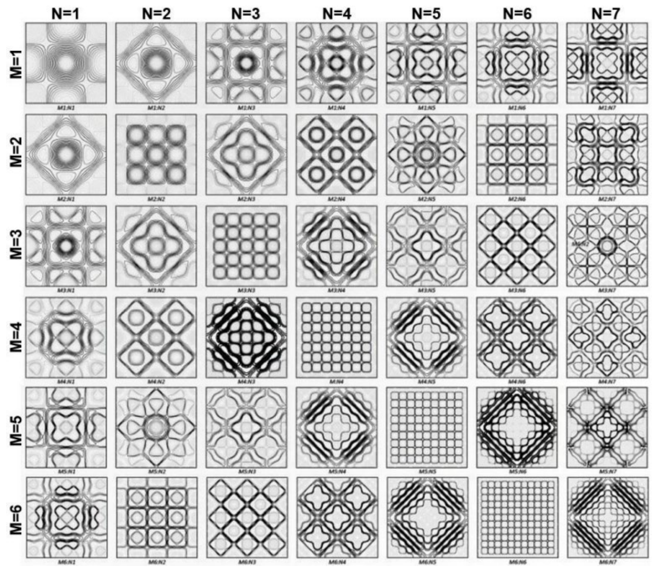


Fig. 10. F*orms resulting from the numerical variations of the variables M and N in the algorithm designed in Rhino and Grasshopper software, each defining the frequency for nodal vibration*s

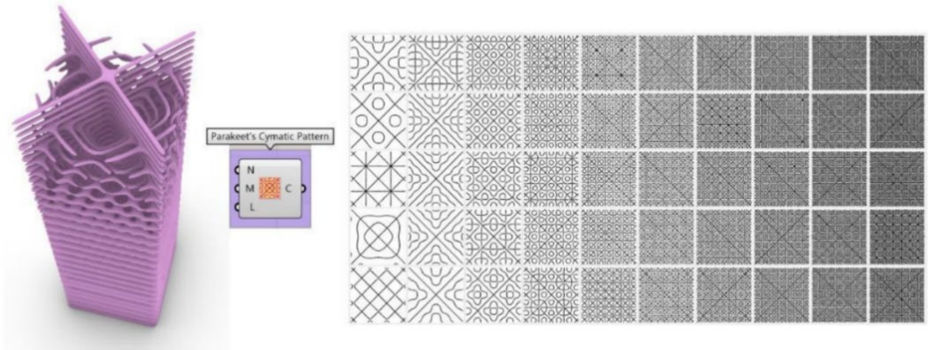


Fig.11*. Three-dimensional form resulting from the numerical variations of the variables MMM and NNN in the algorithm designed in Rhino and Grasshopper software, each defining the frequency for nodal vibrations.*

5. Conclusion

The conclusion highlights a profound connection between architecture and music, seeing architecture as the “music of space” and music as the “architecture of time.” While architecture is three-dimensional and built from tangible materials, music is one-dimensional and metaphysical, yet both share common principles like rhythm, harmony, and proportion. There are two primary approaches to analyzing this relationship: the conceptual, focusing on spatial characteristics, and the formal, examining physical form through frequency and vibration.

Using Ernst Chladni's Cymatic principles, the research demonstrates that each sound frequency can generate unique forms. By applying algorithms, with input variables like sound frequency and material density, parametric architecture transforms musical frequencies into two-dimensional shapes. This mathematical link, facilitated by tools like Rhino and Grasshopper, underscores music as a shared language that bridges the structured frameworks of parametric design with the abstract nature of sound.

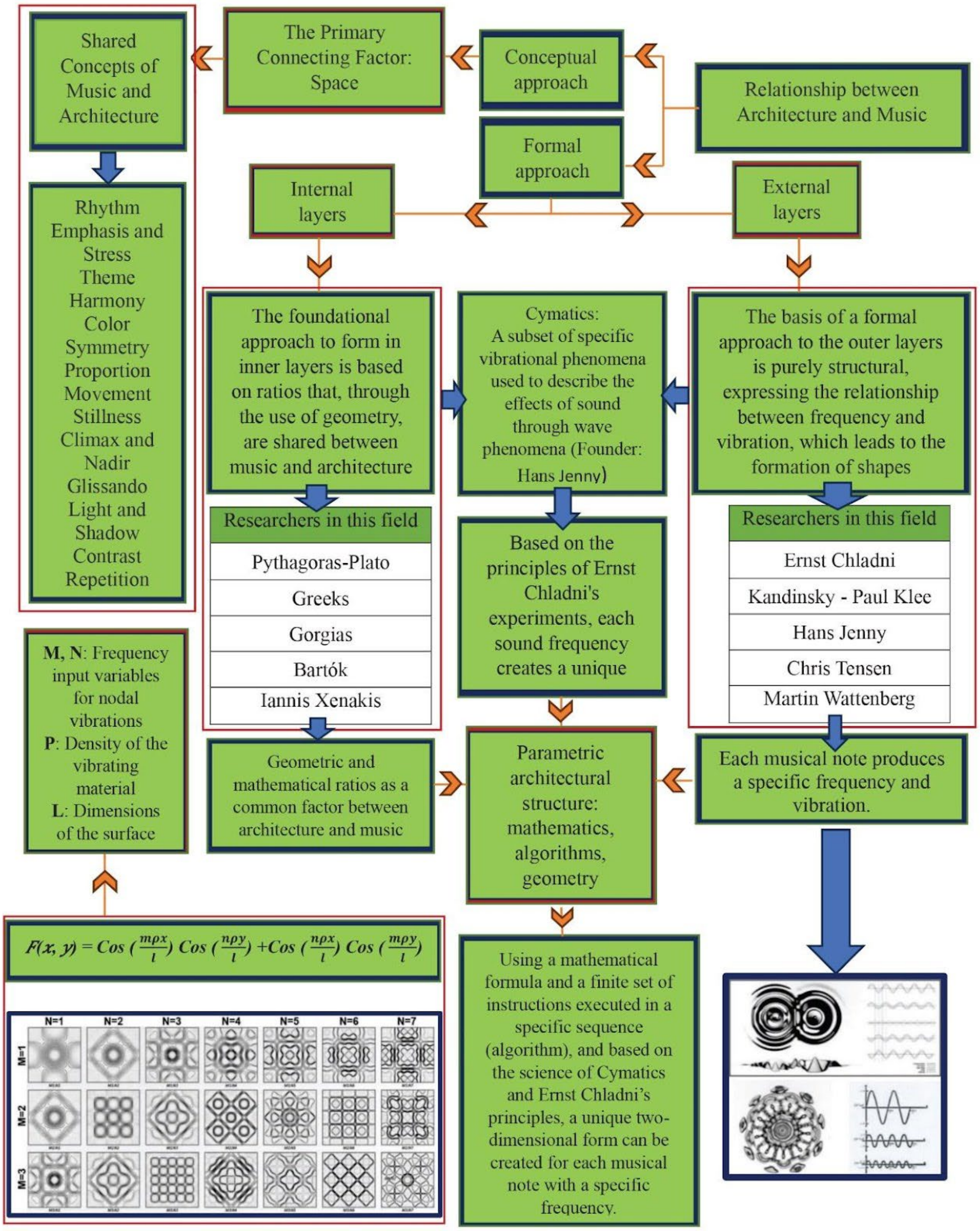


Fig. 12**.** *The relationship between architecture and music and how it connects to parametric architecture with a form-oriented approach.*

Source: Authors

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